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THE
JOURNAL OF GEOLOGY

JANUARY-FEBRUARY, 1895.

THE BASIC MASSIVE ROCKS OF THE LAKE SUPERIOR REGION.

IV. THE PERIPHERAL PHASES OF THE GREAT GABBRO MASS IN NORTHEASTERN MINNESOTA.[1]

C. The Granulitic Gabbros.

THE granulitic gabbros include a large number of different phases characterized by the same general type of structure, but differing from one another in mineralogical composition. Olivinitic varieties occur in small quantity. In these the constituents are the same as those composing the great mass of the normal gabbro, viz., magnetite, olivine, diallage and plagioclase. The rarity of olivine in the granulitic rocks is in marked contrast with its abundance in the gabbroitic variety. In the latter, if one of the components is absent it is usually the diallage. In the granulitic phase, olivine is more frequently absent than present. By its loss diallagic varieties result. But pure diallagic phases of the granulitic rocks are also uncommon, for in the production of the granulitic structure there is a tendency to the formation of biotite and hornblende. Thus biotitic and hornblendic varieties are much more common among the granulitic gabbros than among those with the true gabbro structure. Another quite widely spread constituent in the granulitic rocks is hypersthene. In these, as in the non-feldspathic gabbros, this mineral appears to take the place of olivine.

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[1] Continued from this Journal, Vol. II., p. 825.

The Olivinitic Varieties.—The few olivine-bearing granulitic gabbros studied are from places but a very short distance south of the north limit of the gabbro area, and not far north of localities where the normal gabbro occurs in its usual form. They appear to be intermediate in character between the gabbro and the typical granulitic rocks. Their structure is not purely granulitic, for the pyroxene in them is in polysomatic masses rather than in individual rounded grains, although in the same section there may be found in addition to the polysomatic masses a few isolated grains of augite and some compact plates of the same mineral.

The olivine is in fairly large, colorless or light yellow, irregular grains, whose cleavage cracks are marked by grains of magnetite and masses of limonite. Magnetite also occurs as small dust-like particles in their peripheral portions. Green earthy decomposition products surround many of the fresh olivines and extend into their interiors along irregular cracks, and out into the minerals that are contiguous to them. A feature of great significance in connection with the olivine is the fact that many of its grains are surrounded by narrow rims of augite, just as are the olivine grains in the normal gabbro.[1] Since this method of association of the two minerals is so characteristic for the gabbro, which is undoubtedly an igneous rock, there can be no question that the olivine granulitic rocks, though bedded, are closely related to the gabbro, and like this rock are also igneous, and are not metamorphosed sediments. Unfortunately, most of the granulitic rocks contain no olivine, so that the application of this means of identifying them as portions of the great gabbro is very limited.

The diallage appears to be next in age to the olivine. It is in small rounded grains, either isolated or in aggregates so united as to form large masses. The individual grains of the aggregates are often separated from each other by narrow seams of limonite, or by small grains of magnetite, and in their midst is not infrequently a grain of olivine. The mineral is nearly colorless. It possesses the normal prismatic cleavage of augite, and in addition another that reveals itself as a series of very fine lines parallel to the coarser lines of the prismatic cleavage. Its inclusions are little particles of magnetite, small plates of biotite, tiny masses of green and brown earthy matter and a few glass particles.

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[1] See this Journal, Vol. I., p. 702, Fig. 1, and p. 706, Fig. 3.

The existence in these rocks of an aggregation of many small rounded grains of augite in the place of the large plate of this mineral in the true gabbro is strongly suggestive of the polysomatic augites discovered by Lawson[1] in the diabase of certain dikes in the Rainy Lake region, Canada. In the Minnesota rocks the polysomatization of the augite seems to be an intermediate step in the granulitization of the gabbro, not, however, in the sense that all the granulitic rocks have passed through this stage at some time in their history, but in the sense that the polysomatization of the augite is the result of a force similar in character to that which produced granulitization in the granulitic rocks but less efficient in its action.

The plagioclase of these rocks is in allotriomorphic grains of varied sizes and of very irregular shapes in those portions of sections that are poor in augite, and in small and more or less rounded grains where rounded augites and olivines are found. For the most part the feldspar is quite fresh, but here and there little accumulations of kaolin occur in it, and small bunches of green chloritic substance fill the interstices between the neighboring grains. Under low powers all the plagioclase appears to be filled with dust, but this dust under high power is resolved into long needles and small plates of opaque or dark brown substances, and tiny irregular glass inclusions. A few long, narrow, quadrangular cavities and some elliptical ones seem to be filled with liquid, but they are in all cases so minute that it cannot be certain that this is the case. All the inclusions of this character are usually heaped toward the centers of the feldspar grains, with a zone of clear plagioclase around them. In addition to these inclusions there are also imbedded in the feldspar a few rounded grains of augite, and of magnetite, and along the edges of the last named mineral flakes of reddish brown biotite.

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[1] Proc. Can. Inst. 1887, Toronto, 1888.

As to the nature of the plagioclase it is difficult to draw accurate conclusions. Measurements of the extinction angles of contiguous twinned lamellæ indicate a labradorite. The most noticeable difference between the plagioclase of these rocks and that of the true gabbro is with respect to their twinning bars. In the latter rock the lamellæ are broad and but few in number, and but one set occurs. In the granulitic rocks the striations are narrow and very numerous. Moreover there are two sets of them inclined to each other at angles of about 90°, and the lamellæ in each set frequently wedge out toward the interiors of the grains in which they occur. Again, small areas near the centers of grains will often have two sets of lamellæ crossing each other, while in other portions of the same grains but a single parallel series is found. Such phenomena as these are usually interpreted as pointing to a secondary origin for much of the twinning in plagioclase. In the present instance a secondary twinning accompanying the granulitization of the rock would indicate that both phenomena owe their existence to common causes. Since the rocks are not sheared, the only causes that can be assigned for them are motion within the rock mass and strains produced by rapid and irregular cooling.

The magnetite, as has already been said, is to be found as small grains included in all the other primary components, and also as irregular masses between them. Whenever it comes in contact with plagioclase, there is formed around it a reaction rim of biotite.

There seems to be no definite order of succession in the formation of the various components. Sometimes the order is magnetite, olivine, pyroxene and plagioclase; at other times the plagioclase is older than the pyroxene while younger than the olivine, and again in a few instances the feldspar appears to be even older than the olivine. With respect to the age of their feldspar the granulitic rocks occupy an intermediate position between the gabbros and the diabases, in the former of which rocks the plagioclase is younger than the pyroxene, while in the latter it is the older component.

Hypersthenic Varieties.—Closely related to the olivinitic-granulitic gabbros are the hypersthene-bearing varieties. In some cases these contain a small quantity of olivine, but in most cases hypersthene has entirely replaced this mineral. A few grains of the usual colorless olivine, for instance, may be detected on one edge of the section of rock No. M. 1347, whereas elsewhere in the slide it is lacking. The main portion of the rock consists of more or less rounded grains of hypersthene and diallage, and irregular masses of magnetite, imbedded in a plexus of irregular but nearly equidimensional grains of plagioclase. Magnetite particles are included within all the rock's constituents, and, since these are very fresh, the magnetite is probably a separation from the magna. The mineral also occurs on the edges of the few olivine grains present, but here it is in long stringers that are evidently secondary.

In the great majority of the hypersthene varieties of the granulitic gabbros no trace of olivine may be detected either in the fresh or in the altered state. Their components are usually hypersthene, diallage, feldspar and magnetite. All are fresh, except in very rare cases when the feldspar shows traces of decomposition. The proportions of the pyroxenes vary widely in different specimens, even to the complete exclusion of one or the other of the two varieties. The purely hypersthenic phases are treated with the other hypersthene bearing rocks in this place, while the purely diallagic kinds are reserved for later discussion.

The hypersthene, the characteristic component of these rocks, is remarkably fresh and transparent. It is pleochroic in the usual light green and pinkish tints, and is often so compact that but few cleavage cracks are to be seen in its grains. An analysis by Dr. E. A. Schneider of a very pure powder of the mineral separated from rock No. 7036, one of the best examples of the type without diallage, gave:

SiO_2	Al_2O_3	Fe_2O_3	FeO	MnO_2	CaO	MgO	H_2O (105°)	Total[1]
48.44	7.91	.33	20.88	.92	1.44	19.35	.08	97.35

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[1] TiO_2 was not determined gravimetrically. A colorimetric test showed about .40 per cent. of this oxide present.

The form of the orthorhombic pyroxene determines in large measure the structure of the rock containing it. In the most purely granulitic varieties this mineral is in the small rounded or subangular grains, which, with the similarly shaped diallage grains and those of plagioclase, together with an occasional particle of magnetite, make up the entire rock. The magnetite is included within both of the pyroxenes and the feldspar, and the pyroxenes are often also enclosed within the plagioclase. The sequence is thus magnetite, pyroxene, and plagioclase, with the hypersthene probably older than the diallage. Figure 1 illustrates the structure of a rock of this kind.

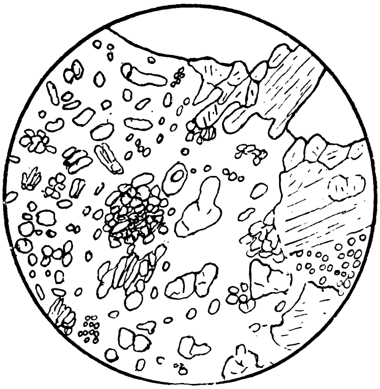

FIG. 1.—Granulitic gabbro, with large grains of green hornblende and small rounded ones of augite in a groundmass of plagioclase that appears in ordinary light to be a homogenous mass. The large plates of mineral to the right are hornblende. No. M 1335, x 87.

A very peculiar type of structure is that resulting from the occurrence of the hypersthene in cellular grains and plates that are larger than the grains of the other constituents, and less rounded than the hypersthene of the more purely granulitic rocks. These large plates and grains are optically continuous over considerable areas, but are physically not continuous, since they are filled with small and large pores containing plagioclase of the same nature as that occurring between the hypersthene. The plates are very ragged along their edges and have many prolongations with rounded ends. The skeleton-like masses of the pyroxene in these rocks are thus very similar in their development to the cellular cordierite, andalusite and orthoclase grains described by Salomon[1] in contact rocks. The cellular structure is thought by this writer to be so characteristic of minerals formed by contact action that he has called it the contact structure. In contact rocks it is probably due to the selection of material needed in building up the contact minerals, which would grow around the substances not needed in their construction and thus include them. In the present case the cellular structure of the hypersthene must be an original one, and the direct consequence of the conditions under which the minerals separated from the rock magma. The plagioclase, though included within the hypersthene, is probably the younger of the two minerals, just as the ice, in a frozen sponge saturated with water, is younger than the mass of the sponge which encloses it.

A third form of structure is produced by the aggregation of the hypersthene plates into groups or masses that are imbedded in the granulitic matrix from which hypersthene is wanting. The masses or groups are composed of large irregular grains of the orthorhombic pyroxene, sometimes cellular, sometimes compact, with which are intermingled many grains of diallage and an occasional one of plagioclase. Figure 2 shows a portion of one of these aggregations in the upper part of the picture. In its lower portion is the granulitic mosaic of plagioclase and diallage.

The diallage in all these rocks is in the rounded granulitic forms, except in the rare instances when it is associated with the hypersthene in the aggregates, where it is in large irregular grains. In certain of the non-hypersthenic varieties it is sometimes in cellular plates, but in those containing the orthorhombic pyroxene the diallage, when it occurs, is nearly always granulitic. In the figure last referred to the small, highly refractive, rounded grains are of this mineral. In nearly all cases the diallage is light green in color, is fresh and is without pleochroism. Its inclusions are magnetite grains, small flakes of brown mica and tiny particles of limonite.

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[1] Zeits, d. d. geol. Ges., XLII., 1890, pp. 487, 511, *et seq.*

The feldspar of these rocks, like their other constituents, is on the whole very fresh. It is nearly always transparent and colorless, but here and there in some sections it contains opaque or cloudy masses of kaolin and grains of quartz. Its grains are approximately equidimensional. They do not interlock with the irregular sutures of granitic feldspar, but they form with each other straight-edged contacts, like the grains of a microgranitic mosaic. In many rocks these grains are of about the same size as the grains of diallage, but in others they are so small that their aggregate between crossed nicols looks very much like a microgranitic groundmass in which the larger pyroxene grains are

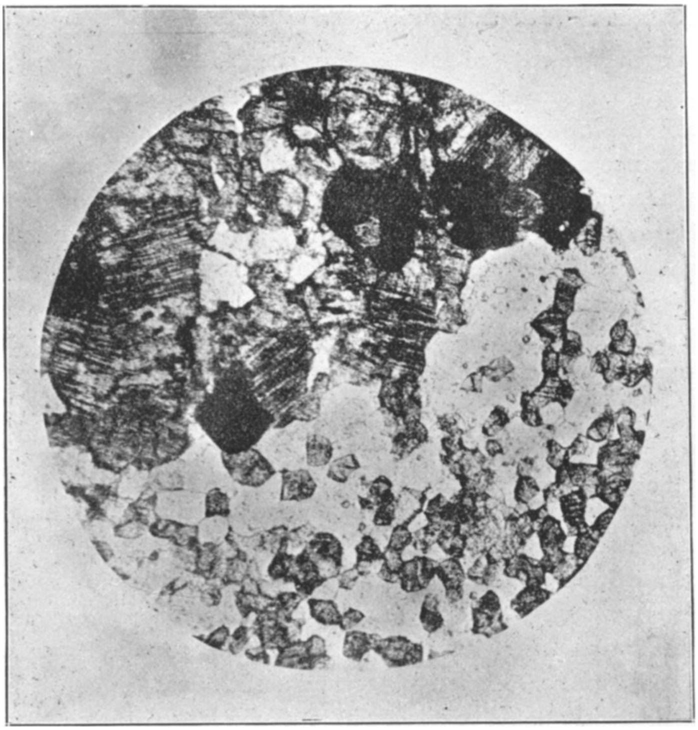

FIG. 2.—Granulitic hypersthene-gabbro with aggregates of pyroxenes. A portion of one of these aggregates is shown in the upper portion of the figure. In the lower part is seen the granulitic mosaic of diallage and feldspar No. 8879.

imbedded. The inclusions discoverable in them are magnetite, small masses of green and brown earthy matter, much of which seems to be in pseudomorphs after magnetite, tiny opaque dust inclusions, small elliptical glass-filled cavities and a few apatite crystals. No liquid inclosures were detected in any of the fresh grains, though a few may be present in those that are slightly decomposed. The twinning of the feldspar is less complicated than was to be expected after studying the olivine-bearing granulitic rocks. Many of the grains are untwinned; more are simple Carlsbad twins; while a few show the more usual parallel bars of the polysynthetic twinning. Most of this feldspar is undoubtedly plagioclase of the same character as is found in the normal gabbro. Its optical properties so far as can be determined are like those of the gabbro feldspar, and the density of a powder separated from rock No. 8879 is 2.715. Some of the untwinned feldspar may be orthoclase, as analyses of some of the hypersthenic granulitic rocks show a large percentage of potassa.

The remaining primary component of these rocks is magnetite. It is found as tiny inclusions in the other constituents and as large grains between them, and sometimes within the pyroxene. The outlines of the grains often show traces of crystalline forms, but almost as frequently they exhibit none.

In addition to the minerals mentioned there is also often present a comparatively large quantity of biotite, but in the hypersthene varieties it seems to be less abundant than it is in those containing none of this pyroxene. When present it is in brownish green flakes so intimately associated with the hypersthene and diallage that it must needs be regarded in some cases as an alteration product of them. Not only are the little flakes abundant on the peripheries of the pyroxene grains, but they are also disseminated all through their substance as very small ill-defined specks whose strong pleochroism and brown color proclaim them to be biotite. In other rocks, in which the pyroxenes are fresh, the biotite is completely wanting, but in No. 7036, one of the freshest of all the granulitic rocks examined, the mica is very plentiful, particularly in the feldspar, as brown wisps and plates.

In this particular case, and in others like it, the biotite seems to be original, at any rate there is no evidence that it is secondary.

Chlorite is another of the unessential components of the granulitic rocks. It is however always in such small quantity that its effect upon the general aspect of these rocks is not marked.

The analyses of two specimens of the hypersthenic rocks follow:

	I.	II.
SiO_2	46.96	49.56
TiO_2	.62	.48
Al_2O_3	14.13	17.81
Cr_2O_3	tr.	
Fe_2O_3	.76	2.76
FeO	14.95	9.48
NiO	.06	
MnO	.93	.06
CaO	2.32	9.70
MgO	15.97	5.93
K_2O	1.68	
Na_2O	.35	2.87
H_2O at 105°	.07	.50
H_2O above 105°	1.26	
P_2O_5	.03	.67
Total	100.09	99.82
Sp. Gr.	3.193	2.967

I. Granulitic hypersthene-gabbro. Very rich in hypersthene and biotite and poor in feldspar. Much of the latter is unstriated. Analyzed by Dr. H. N. Stokes. No. 7036.

II. Granulitic diallage-hypersthene-gabbro. Diallage much more abundant than hypersthene. No mica. Most of the feldspar striated. Analyzed by W. H. Melville. No. 8879.

Diallagic Varieties.—The great majority of the granulitic gabbros contain neither olivine nor hypersthene. These rocks consist essentially of diallage and plagioclase, or of these minerals with biotite and hornblende. The varieties without the last two named minerals are not as common as those containing them. Indeed, only three sections of diallage rocks free from biotite have been seen, and in these the structure is slightly different from that of the typical granulitic rocks. The plagioclase in them is more or less lath-shaped and the augite grains in many cases possess idiomorphic outlines. In section M. 458 H. for instance, the pyroxene occurs in two forms, viz., in small fresh, greenish, partly idiomorphic grains that produce with the small more or less lath-shaped grains of plagioclase a granulitic aggregate, and in large altered crystals, filled with magnetite. The outlines of many of these larger grains are clearly the result of the crystallizing force, but, nevertheless, they are not sharply defined, since their peripheries are slightly granulated (Fig. 3). Within the granulated portion, however, the original contours of the crystals remain, so that the granulated peripheries are not properly granulated portions of the original crystals, as in the cases described by Professor Judd,[1] but are rather additions made by small grains adhering to the exteriors of the large crystals. In the Scottish occurrence the interiors of the grains did not assume a definite crystallographic form before the granulated pyroxene was produced. Here the homogeneous nucleus passes gradually into the granulitic portion in consequence of "Crystallization having gone on to a certain extent, while the [rock] mass

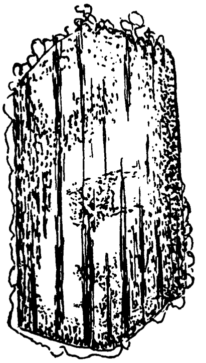

FIG. 3.—Idiomorphic pyroxene in granulitic gabbro, surrounded by granulitized augite. M. 458 H. x. 30.

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[1] l. c., Fig. 4, Pl. VII., p. 94.

was in a state of perfect internal equilibrium," and then having been concluded, after some internal movement or strain had been set up within it. In the Minnesota rock the crystal of pyroxene was completely formed before the granulated portion was added to it. The crystallization of the diallage took place in two distinct stages, first, while the rock's material was in a state of internal equilibrium, during which period the perfected crystal was formed ; and, second, at some more recent period, when a change in the conditions under which the rock-mass existed afforded a favorable opportunity for the formation of a second generation of augite, which took the form of granulitic grains. The crystal above pictured is the most perfect one in the section. Others no longer possess such a distinct outline. An interior nucleus heavily charged with magnetite or black earthy decomposition products is surrounded by a clearer zone of light green pyroxene with few inclusions of any kind, and this in turn passes into the granulitic material; or a fairly clear interior may be surrounded by a zone of decomposition substance, marking the outline of the original crystal, and this be enveloped by a clear zone with its attendant granulitic periphery. In all cases, however, it is plain that the pyroxene separated from the rock-mass in two entirely distinct stages.

The second generation of diallage forming, with the plagioclase, the granulitic groundmass in which the larger grains lie, is in very light green, almost colorless grains measuring from .03 to .15 mm. in diameter. They are usually longer than they are broad, thus giving rise to short prismatic forms, on which occasionally crystal faces may be detected. They include small particles of magnetite and are themselves often enclosed in plagioclase.

The last named mineral likewise appears to be in two generations. At any rate it occurs in good-sized lath-shaped grains, and in smaller ones with badly defined rounded outlines. Magnetite is included in both varieties in large quantity.

Of the few remaining components magnetite and biotite are the most important. The former is in large irregular grains between the diallage and plagioclase, and in small grains or particles included within them. Much of it may be primary, but most of it is undoubtedly secondary. The biotite is found principally between magnetite and plagioclase as a reaction rim around the former mineral, although in some instances it appears to replace pyroxene.

In many specimens of these rocks the pyroxene is quite fresh. In other sections the diallage has undergone a change by which hornblende has resulted. This is in the brownish-green indefinitely outlined flakes and plates characteristic of secondary hornblende. It occurs principally in the outer portions of the larger crystals, but sometimes it extends inward until it replaces their entire substance. The granulitized augite of the groundmass in which the porphyritic crystals are imbedded is also occasionally changed into hornblende, but only when in the near vicinity of the larger grains. Most of the granulitic augite is unaltered.

Biotitic and Hornblendic Varieties.—As the biotite and hornblende in the granulitic rock increase in amount the pyroxene decreases until the first two minerals begin to affect materially the character of the rock and to give it a distinctive aspect in the thin section. Sometimes the biotite occurs unaccompanied by hornblende, though this is rarely the case. It usually occurs together with the amphibole, with the latter in no inconsiderable quantity.

The biotite is in two forms, either as small plates with the general outlines of small granulitic augite grains, or in larger very irregular flakes, many of which are so closely associated with magnetite that they must be considered as having originated through its alteration. The smaller plates of the mica and much of the material of the larger ones are very probably alteration products of pyroxene. The former have the same shapes as the granulitic grains of this mineral, while the latter often seem to grade insensibly into comparatively fresh augite substance. Some of the plates surround cores of fresh diallage from which they are separated by a sharp line and some occur as well-defined plates scattered indiscriminately among the components of a perfectly fresh rock. These are probably original.

Nearly all of the hornblende that appears in these sections is quite evidently an alteration product of the augite. It is in large plates of a dirty greenish or a greenish brown color, according to the position above the lower nicol. The outlines of these plates are always ragged, and they bristle with projections that extend beyond the main mass of the plate far between the neighboring plagioclase grains. As the augite changes into hornblende, the new substance produced orientates itself uniformly until the products of a dozen or so grains become merged into a single plate, which naturally includes a large number of feldspar and magnetite grains, and of biotite flakes, provided any of these happen to have been formed before the hornblende. The structure of the plates is exactly analogous in its origin to that of Salomon's contact minerals, as it is here produced by selection of augite grains and the enclosure of those minerals that were not suitable for alteration into amphibole. When the small grains of augite are too widely scattered to affect the hornblende produced by their alteration, this substance occurs in isolated particles with independent orientations. That these little isolated grains are secondary in their origin is learned from the fact that many of the granulitic augites are partially changed into the same mineral, some only on their edges, and others throughout nearly their entire masses. In many other sections the hornblende is evidently original, in which case it has the same properties as the least decomposed of the secondary amphibole. In rock No. 7061 for instance the hornblende is more irregular in its outline than the diallage, though it usually possesses right-lined contours rather than sinuous ones. In color it is brownish green with absorption as follows: $\mathfrak{c}=\mathfrak{b}=$brownish-green$>\mathfrak{a}=$ pale yellow. Its grains occur between those of plagioclase, and they include magnetite, diallage and round or elliptical colorless inclosures like those observed within the pyroxene. Cross sections of crystals with the characteristic contours and cleavage of hornblende are not very uncommon. Although this hornblende is not unlike the secondary amphibole in others of the granulitic rocks it is not possible to regard it as due to the alteration of augite or of any other mineral now occurring in the rock.

In those phases of the granulitic rocks that contain large quantities of biotite and hornblende, the former mineral is often in large plates with irregular outlines and the cellular structure that has been referred to so frequently as characteristic of the constituents of these rocks. On its basal section the mica is reddish brown. Parallel to the cleavage it is almost opaque, while perpendicular thereto it is yellow. It includes grains of augite and is often included in plagioclase. Most of the diallage in these rocks has disappeared and has been replaced by yellowish brown hornblende in grains of the same shape and size as the few augites remaining. In some sections that are otherwise quite fresh, individual augite grains are changed into hornblende often to half their extent. At some distance from their contact on either side of it the augite and the hornblende are well characterized. Near the contact their special peculiarities blend to form an intermediate substance that is neither a well defined pyroxene nor a typical amphibole. The structure of most of these varieties of the granulitic rocks is typically granulitic. There are a few cases, however, in which a departure from this structure is noticed. In rock No. 8900, for instance, the plagioclase grains are not all of nearly the same size. Large grains, with very ragged contours and small grains of the granulitic character are both common in it. The former measure between .5 and 1. mm. in length and the latter rarely more than .1 mm. No distinction as to age between the two feldspar can be made out. Sometimes the large grains seem to be younger than the small ones, and often they appear to be older. Both are more or less kaolinized and both include augite, hornblende, small colorless crystals and glassy particles. The other exceptions to the characteristic granulitic type are no more striking than is this.

Non-feldspathic Varieties.—The only granulitic rock free from plagioclase is No. 1334, which has already been referred to in another place (Vol. II., p. 824). This rock is more or less schistose. It is composed almost exclusively of colorless pyroxene and colored hornblende. Most of the latter mineral is of the character already so frequently described, but there is in addition a little bright green amphibole fringing areas of the brownish green variety. The fresh augite and the hornblende are both principally in small rounded grains closely packed together, producing a mosaic, polarizing brilliantly between crossed nicols. Locally in the section the augite granules unite to form a fairly compact plate of this substance. In one place a large nucleus of compact augite is surrounded by a broad irregular zone of small grains of exactly the same substance. The interior is crossed by many irregular lines that divide it into a large number of small grains, but all of these are uniformly orientated, and between crossed nicols they polarize together. In the outer zone the individual grains are slightly removed from one another, and consequently each polarizes independently of all others. In a recent description[1] of this rock it was intimated that the granulitic outer zone had been caused by the fracturing of the large augite grain and the movement of the broken portions from their original positions. A more careful inspection of the section teaches that this may not be the method of formation of the peripheral granulitic zone. Movement in the rock-mass during consolidation of the granules and posterior in point of time to the formation of the nucleus has certainly been instrumental in causing the complex orientation of the granules in the outer zone, but that these latter represent fragments of an original large grain is not now believed.

D. Conclusion.

The above-described phases of the gabbro have been discussed in more detail than their petrographical interest would seem to justify, mainly because their eruptive origin appears to have been called into question.

The microscope has shown so conclusively that the rudely bedded basic and fine-grained dark rocks, interlaminated with the quartzose bands along the northern border of the normal gabbro, are but phases of the latter rock, that a thorough field study of the relations existing between these rocks and the gabbro does not seem necessary to their correct understanding, however much it may be desirable. All the field work which has been done in the neighborhood of Akeley Lake, however, so far as it goes, confirms the conclusions of the microscope. A map of this region has kindly been furnished the writer by the Minnesota Survey through the courtesy of Dr. U. S. Grant. It is reproduced in Fig. 4.

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[1] Geol. and Nat. Hist. Survey of Minn. 19th Ann. Report, p. 196.

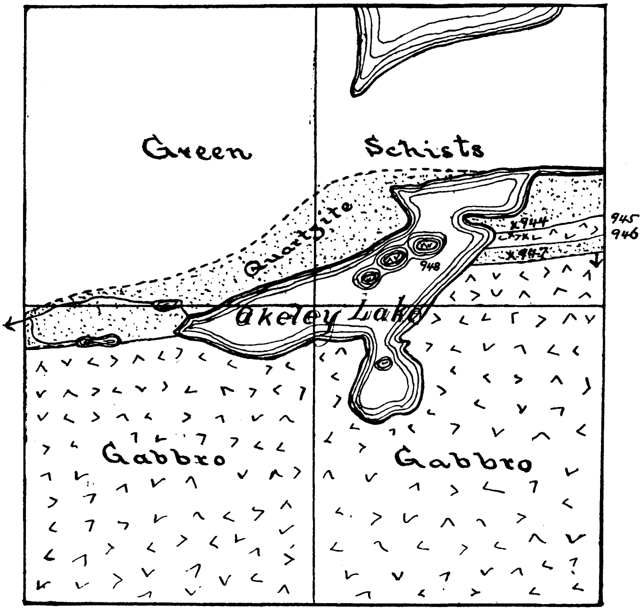

FIG. 4.—Preliminary geological map of the vicinity of Akeley Lake, Sec. 29, T. 65 N., R. 4 W., Minnesota. From manuscript map furnished by Dr. U. S. Grant, of the Minnesota Survey. Scale, 3 inches to mile.

The rock south of the lake is the normal olivine gabbro. On its northern side this is in contact with the crystallized quartz-olivine-pyroxene rocks, to which reference has already been made (Vol. II., p. 816). On the map they are marked "quartzite." Between the main masses of the "quartzite" and the gabbro a repetition of bands of these two rocks intervenes, so that the gabbro area appears to pass gradually into the "quartzite" area. Two large bands are shown on the map, to the east of the lake, but these bands are not composed exclusively of the quartzose rock or of gabbro. The gabbro band contains on its borders small bands of "quartzite," while the large "quartzite" band is interlaminated with several narrow bands of gabbro. When thick these interbanded gabbros are similar in every respect to the normal gabbro further south, except that they may contain more hypersthene; when thin they are basic or granulitic phases of this rock.

The quartzose rocks contain a large quantity of gabbro material, such as olivine, diallage, hypersthene, etc., which can only have come from the gabbro in contact with them. The origin of these rocks has not yet been worked out.

Of the specimens indicated on the map No. 944, from the southern edge of the northern "quartzite" area is a quartzose rock saturated with gabbro material, and interbanded with narrow seams of granulitic gabbro. No. 495, near the contact between this rock and the large gabbro band, is a granulitic gabbro, with a diabasic structure in places. No. 946, from the center of this band, and No. 948, from the easternmost island in the lake, are normal gabbros containing some hypersthene. No. 947 is like No. 944.

Before concluding this discussion it seems necessary to refer to some misconceptions that have arisen with respect to the author's position regarding the Pewabic quartzite.[1] In the nineteenth report of the Minnesota Survey he describes a few specimens sent him by Professor Winchell from the vicinity of Akeley Lake. Some of these were labeled "Muscovados" and others "Pewabic quartzite," and were referred to under these names in the annual reports of the Survey. The "muscovados" were found, upon microscopical examination, to be mainly phases of gabbro, and the "quartzites" to include two distinct rocks, viz., granulitic and basic gabbros and quartzose rocks like those referred to above as "quartzites" in the account of the geology of Akeley Lake. Hence it was concluded that the "Pewabic quartzite," *as described from the Akeley Lake region*, could not be used as a definite horizon for correlation purposes, since so much of it is gabbro. This opinion is still held; but the writer may have been mistaken in his views regarding the origin of the quartzose rocks interbanded with the gabbros. None of those seen, are, in their present condition, fragmental sediments, nor can any trace of clastic grains be detected in them. Nevertheless, it is possible that they may be re-crystallized quartz rocks.

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[1] W. S. BAYLEY: Nineteenth Ann. Rep. Geol. and Nat. Hist. Survey of Minn. Pp. 193–210.

The basic layers interbanded with the quartzose ones are, however, not "tufaceous, eruptive fragmental elements,"[1] and cannot be a part of any distinct horizon to which the name Pewabic quartzite may be applied. These bands are igneous and are not chemical sediments, nor are they metamorphosed quartzites.

The main purpose of the paper referred to, however, was not the discussion of the Pewabic quartzite. It was the determination of the age of the gabbro, and upon this question it was supposed to have added some evidence in opposition to the view that the gabbro is of Animikie age, although Professor Winchell[2] was inclined to regard its evidence as favorable to that view.

The descriptions of the granulitic and basic gabbros so closely associated with the normal gabbro show that these rocks are not sediments, but are parts of the gabbro, and hence cannot be used for determining the age of the latter rock.

If the quartzose rocks with which they are interbanded are metamorphosed Animikie strata then the proof of the post-

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[1] PROFESSOR N. H. WINCHELL: Footnote, 19th Ann. Rep. Geol. Survey Minn., p. 210.

[2] "Of course the intent of Professor Bayley's paper is to establish the idea of Professor Irving that the gabbro flood is later than the Animikie rather than near the bottom of it, where the Minnesota geologists have placed it, but its purport confirms the Minnesota geologists in their conclusions."—*Professor Winchell, in footnote referred to.*

Animikie age of the gabbro is conclusive. As further evidence on this question Dr. Grant[1] reports that in the neighborhood of Gunflint Lake "the gabbro was found to include fragments of the Animikie slates, and it also was found directly overlying and in contact with beds of the upper member of the Animikie. This gives additional proof of the post-Animikie age of the gabbro."

W. S. BAYLEY.

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[1] 22d Ann. Rep., p. 77.